Marginal and internal fit of pre-sintered Co-Cr and zirconia 3-unit fixed dental prostheses as measured using microcomputed tomography

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Abstract: STATEMENT OF PROBLEM Limited information is available on the precision of new metal processing technologies. PURPOSE The purpose of this in vitro study was to evaluate the marginal and internal fit of pre-sintered cobalt-chromium (Co-Cr) and zirconia 3-unit fixed dental prostheses using x-ray microcomputed tomography. MATERIAL AND METHODS Three-unit fixed dental prostheses were prepared on metal dies (N=12) using a typodont model from the maxillary first premolar to the first molar. A standardized preparation with a 1.2-mm chamfer (360 degrees) and a 2-mm occlusal reduction was prepared on abutment teeth. The dies were scanned and divided into 2 groups to receive the fixed dental prostheses (n=6) made of pre-sintered Co-Cr and pre-sintered zirconia. Each framework was seated on its cast, and marginal and internal discrepancies were measured at 9 points, starting from the most distal point from the pontic for the maxillary first premolar and the first molar (points 1-4, mesial; point 5, occlusal; points 6-9, distal) of each abutment tooth using microcomputed tomography. The data were analyzed using the Levene test, t test, and ANOVA (=.05). RESULTS When overall mean discrepancy values were compared, no significant difference was observed between pre-sintered Co-Cr and pre-sintered zirconia (P=.085). Discrepancy values for points 1, 2, and 3 were significantly different for pre-sintered Co-Cr and pre-sintered zirconia, with the lowest mean values for point 1 and the highest for point 5. On the abutment tooth basis, for the maxillary first premolar and the first molar, a significant difference was found only in points 6 (P<.001) and 8 (P<.003) for both materials. When the discrepancies for the maxillary first premolar were considered for pre-sintered Co-Cr and pre-sintered zirconia, the mean values were significantly different only at points 1 (P<.001), 2 (P=.007), and 3 (P=.003) and were smaller for pre-sintered zirconia. For the tooth the first molar, a significant difference was observed at point 2 (P=.002) and point 3 (P=.008) for both materials, where the mean values were higher for pre-sintered Co-Cr than for pre-sintered zirconia. The pairwise comparison between points showed a significant difference between measurement points within each material (P<.05). The increase in values between points 1 and 5 was evident for both pre-sintered Co-Cr and pre-sintered zirconia materials. CONCLUSIONS Three-unit fixed dental prostheses made of pre-sintered Co-Cr or zirconia showed similar marginal and internal discrepancy values, with the highest discrepancy values at the occlusal region in both the first premolar and first molar.

DOI: https://doi.org/10.1016/j.prosdent.2018.01.006

Originally published at:
Daou, Elie E; Ounsi, Hani; Özcan, Mutlu; Al-Haj Husain, Nadin; Salameh, Ziad (2018). Marginal and internal fit of pre-sintered Co-Cr and zirconia 3-unit fixed dental prostheses as measured using microcomputed tomography. Journal of Prosthetic Dentistry, 120(3):409-414.
DOI: https://doi.org/10.1016/j.prosdent.2018.01.006

Marginal and internal fit of 3-unit fixed dental prosthesis made of pre-sintered Co-Cr and zirconia measured using micro-computed tomography

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ACKNOWLEDGMENTS

The authors acknowledge Dr.Michael Tholey and Mr.Enno Bojemuller from VITA Company for their precious help in samples scanning. Special acknowledgment goes to Mrs.Rita Hoffmann from AmannGirrbach Company for materials support.

JPD-16-831

Marginal and internal fit of presintered Co-Cr and zirconia 3-unit fixed dental prostheses as measured using microcomputed tomography

ABSTRACT

Statement of problem. Limited information is available on the precision of new metal processing technologies.

Purpose. The purpose of this in vitro study was to evaluate the marginal and internal fit of presintered Co-Cr and zirconia 3-unit fixed dental prostheses (FDPs) using x-ray microcomputed tomography (micro-CT).

Material and methods. Three-unit FDPs were prepared on metal dies (N=12) using a typodont model (Frasaco) from the maxillary first premolar (Z4) to the first molar (Z6). A standardized preparation with a 1.2-mm chamfer (360 degrees) and a 2-mm occlusal reduction was prepared on abutment teeth. The dies were scanned and divided into 2 groups to receive the FDPs (n=6) made of presintered Co-Cr (Ceramill Sintron; Amann Girrbach AG) (CS) and presintered zirconia (Ceramill Zi; Amann Girrbach AG) (CZ). Each framework was seated on its cast, and marginal and internal discrepancies were measured at 9 points, starting from the most distal point from the pontic for Z4 and Z6 (1-4: mesial, 5: occlusal, 6-9: distal) of each abutment tooth using micro-CT. The data were analyzed using the Levene *t* test and ANOVA (α=.05).

Results. When overall mean discrepancy values were compared, no significant difference was observed between CS and CZ (*P*=.085). Discrepancy values for points 1, 2, and 3 were significantly different for CS and CZ ,with the lowest mean values for point 1 and the highest for point 5. On the abutment tooth basis, for Z4 and Z6, a significant difference was found only in points 6 ($P<.001$) and 8 ($P<.003$) for both materials. When the discrepancies for Z4 were considered for CS and CZ, the mean values were significantly different only at points 1 ($P<.001$), 2 ($P=.007$), and 3 ($P=.003$), being smaller for CZ. For the tooth Z6, a significant difference was observed at point 2 ($P=.002$) and point 3 ($P=.008$) for both materials, where the mean values were higher for CS than for CZ. The pairwise comparison between points showed a significant difference between measurement points within each material ($P<.05$). The increase in values between points 1 and 5 was evident for both CS and CZ materials.

Conclusions. Three-unit FDPs made of presintered Co-Cr or zirconia showed similar marginal and internal discrepancy values, with the highest discrepancy values at the occlusal region in both the first premolar and first molar.

CLINICAL IMPLICATIONS

Except for the occlusal region, marginal and axial discrepancy values for presintered Co-Cr or zirconia 3-unit FDPs, did not exceed a clinically acceptable 100 µm. Dentists should always control and adjust the occlusal discrepancies of FDPs made of zirconia or metal-ceramic in the premolar or molar region.

INTRODUCTION

Cobalt-chromium (Co-Cr) is commonly used in dentistry because of its biocompatibility, high strength, low price, and the availability of different fabrication methods.[1,2] However, few studies have focused on long-term effects such as the precision of fixed dental prosthesis (FDPs), biocompatibility, and the new fabrication methods of this material.[3,4] Absence of fit may induce secondary caries, periodontal problems, and pulpitis.[1,2,5-10]

Different definitions of fit have been proposed[5,11] and crowns or FDPs may fail to fulfill the required optimal precision using conventional casting techniques.[1,12,13] Digital techniques provide advantages by eliminating operator factors and improving precision.[1,6,14-16] However, precise guidelines are lacking regarding cement film thickness.[17] A threshold of 120 µm has been accepted as the maximum acceptable marginal discrepancy for single crowns,[10,18-20] but marginal fit values differ depending on measurement location and restoration material type.[10,21] The clinical fit of ceramic and metal-ceramic FDPs and mean marginal discrepancy values vary from 54 to 95 µm.[22-24] Investigations with zirconia FDPs have reported mean marginal discrepancy values in the range of 9 µm to 110 µm.[20,25-27] The increase in cement or internal space could reduce the fracture strength of the restoration and increase failures of the veneering material.[28-30]

Using laser melting technology, single crowns made of Co-Cr have shown marginal discrepancies of between 74 µm and 99 µm and internal discrepancies between 250 µm and 350 µm,[31] while laser-sintered Co-Cr crowns have shown a mean internal discrepancy of 63 µm.[2] Co-Cr is a low-weight alloy, and the risk of distortion increases with the increased length and density of the FDPs.[32,33] Computer-aided design and computer-aided manufacturing (CAD-CAM) methods have been introduced to replace the lost-wax technique[32] for Co-Cr frameworks, either by using direct laser metal sintering (DLMS) or by milling the frameworks from a block.[1,2] Advantages of CAD-CAM include simplicity during the fabrication process, reduced costs, and reduced manufacturing time.[3,34] Co-Cr frameworks can be milled out of either partially or densely sintered prefabricated blocks. Milling from fully sintered blocks produces more accurate precision restorations, although with higher wear rates of the milling burs.[20,35] Using partially sintered blocks can increase the efficiency of the milling process, but the restorations are milled larger by the CAD-CAM system to compensate for the sintering shrinkage.[20,35-36] Whether this compensation is effective remains unclear, especially in the fabrication of long-span FDPs.[23,35]

Scanning, software designing, milling, and sintering are used in CAD-CAM techniques, and all affect the precision of the restoration. Studies have concluded that the internal adaptation of CAD-CAM restorations is less than the marginal fit.[20.23.36] Milling a soft metal block (SMB) with an in-office milling machine has been recently introduced for FDP frameworks.[37] According to the manufacturer, this nonprecious metal has revolutionized the manufacturing process as the wax-like texture of the SMB (Ceramill Sintron; Amann Girrbach AG) allows it to be milled effortlessly with in-office desktop machines. The procedure is said to result in homogenous, distortion-free frameworks without contraction cavities and with shrinkage of 11% during sintering.[38]

Marginal and internal fit of indirect restorations has been evaluated using different techniques.[39-41] Clinical marginal fit can be estimated directly or indirectly with epoxy resin replicas using optical or scanning electron microscopy.[42-44] Laboratory studies have evaluated fit by sectioning tooth-restoration specimens.[20,28,45] Recently, a measuring technique based on microcomputed tomography (micro-CT) was proposed for adaptation evaluations as it allows 2D and 3D investigations at multiple sites and directions in a given specimen.[36,46-49]

The purpose of this study was to compare the marginal and internal fit of presintered Co-Cr and zirconia 3-unit FDPs using micro-CT technology. The null hypothesis was that no significant difference would be found in marginal and internal discrepancy between presintered Co-Cr and zirconia.

MATERIAL AND METHODS

A typodont model (Frasaco A3; Frasaco) with a missing maxillary right second premolar was used. The first maxillary premolar (Z4) and first molar (Z6) were prepared with a standardized chamfer preparation (360 degrees) using a surveyor with a high-speed air turbine under water spray (K9 Milling Apparatus-990; Kavo). Using 25-µm fine grit diamond rotary instruments (Komet Dental),[50] the proximal, labial, and lingual surfaces were reduced by 1.2 mm, the occlusal surface by 2 mm, and the line angles rounded. A silicone impression (Optosil; Kulzer) made before the preparation was used to control the axial reduction. A polyether (Impregum; 3M ESPE) definitive impression was made in a metal stock tray (U3 #141163 Orbilock; Orbis Dental). Melted hard wax (Preci, DIP, Yeti Dental Produkte GmbH) was poured in the impression to obtain a master model. This master model was duplicated 12 times to produce Co-Cr working models (Solidur CoCr; Yeti Dental Produkte GmbH)[49] using the lost-wax technique.[51] These models had 2 abutments on a platform (length: 30 mm, width: 17 mm thickness: 4.5 mm).[25] The specimens were examined for defects, air bubbles, distortions, and fins with a ×10 stereomicroscope (Stereoscopic zoom microscope; SMZ-1000).

The dies were divided into 2 groups of 6 specimens each, according to the material selected. Presintered CAD-CAM Co-Cr 3-unit FDPs (Ceramill Sintron; Amann Girrbach AG) (Group CS) and presintered CAD-CAM zirconia 3-unit FDPs (Ceramill Zi; Amann Girrbach AG) (Group CZ). Each specimen in groups CS and CZ was labeled and digitized using a scanner (Ceramill map 400; Amann Girrbach AG). The data were then imported, and the design of the frameworks was made using the corresponding software (Ceramill Mind; Amann Girrbach AG). A basis design for all models and materials was used to provide adequate space for the connectors between the abutment teeth in the occlusal direction and adequate space for the pontic to the surface of the model. The fabrication parameters for the 3-unit posterior FDP were chosen to comply with requirements for all materials (framework and veneering materials), with a minimum connector cross-section of 9 mm² and a minimum wall thickness of 0.6 mm. After the design, the data were sent to the milling device (Ceramill Motion 2; Amann Girrbach AG).

Ninety-six images were generated using micro-CT scanning, where each FDP was seated on the original stainless-steel model and scanned (CT-MINI) system (CT-MINI; Procron X-Ray GmbH) equipped with a 2-megapixel detector (MOS sensor C7921CA-02; Hamamatsu). The scanning parameters were as follows: accelerating voltage: 130 kV, current: 300 µA, exposure time: 5000 ms per frame, 1 mm Al filter, and rotation step: 0.45 degrees (360 degrees rotation), image pixel size: 21.43 µm.

The reconstruction was evaluated using a software program (VOLEX6; Fraunhofer EZRT) and analyses were made with software (Volume Player Plus 6.5.3.0; Fraunhofer EZRT). Abutments Z4 and Z6 were measured independently to offer higher image quality at higher magnification. The images were obtained at the same position, with a cross-section (YZ-direction, mesial to distal), at 2 different brightness levels. The scale was the length of the voxel sides with 21 µm (Fig. 1). The same cross-section plane was used.

The measurements were made with software (Image J; National Institutes of Health).[42] One calibrated observer (E.E.D.) performed all the measurements, as the presence of small radiographic artifacts precludes the use of automation. Therefore, the measurements were made manually, but the locations were standardized to minimize error. Nine measuring points were selected, starting from the most distal point from the pontic for Z4 and Z6[5,16] (Fig. 2). Point 1 marginal discrepancy described the perpendicular from the internal crown surface to the die margin, while point 2 involved the chamfer area, 800-µm occlusal to the die margin. Point 3 at the axial wall described the internal fit at the midpoint of the axial wall, and point 4 measured the axial-occlusal transition area. Point 5 was the center of the occlusal surface, while points 6, 7, 8, and 9 were the contralateral points of points 4, 3, 2, and 1 on the same abutment.

Statistical software (IBM SPSS Statistics, v23.0; IBM Corp) was used. Discrepancy values between the materials and the abutments were compared using the Levene test, and *t* test. ANOVA and Bonferroni were used for multiple pairwise comparisons. Discrepancy values between materials and abutments were compared using *t* tests. Equality of variances was assessed using the Levene test (α=.05 for all tests).

RESULTS

When overall mean discrepancy values were compared, no significant difference was observed between CS and CZ (*P*=.085) (Fig. 3). Discrepancy values for points 1, 2, and 3 were significantly different for CS and CZ (Table 1), with the lowest mean values for point 1 and the highest for point 5. On the abutment tooth basis, Z4 and Z6 showed a significant difference only in points 6 (*P*<.001) and 8 (*P*=.003) for both materials (Table 1). When the discrepancy for Z4 was considered for CS and CZ, the mean values were significantly different only at points 1 (*P*<.001), 2 (*P*=.007) and 3 (*P*=.003), being smaller for the CZ (Table 2). For the tooth Z6, significant difference was observed at point 2 (*P*=.002) and 3 (*P*=.008) for both materials, where the mean values were higher for CS than for CZ (Table 2). The pairwise comparison between points showed significant difference among measurement points within each material (*P*<.05) (Table 3). The increase in values between points 1 and 5 was evident for both CS and CZ materials.

DISCUSSION

This study compared the marginal and internal fit of presintered Co-Cr and zirconia 3-unit FDPs using micro-CT technology. Based on the results, overall discrepancy values were not significantly different between the materials but significant difference at several measurement points were found between abutment teeth for each material. Thus, the null hypothesis tested was partially rejected.

Variations in the measurement method, specimen size, tooth selection, or specimen design in studies measuring the marginal and internal fit of CAD-CAM Co-Cr frameworks makes direct comparison difficult.[15,16] The marginal discrepancy values found in this study were lower than the those at other measurement points. Similar results were reported in a previous study on anterior crowns using the replica technique for measurement.[4] Measurements on Procera crowns in vivo revealed greater discrepancies in the buccolingual direction and in proximal locations than discrepancies measured in vitro.[37,50]

The goal of CAD-CAM technology is to produce restorations with similar precision to that of traditional metal-ceramic FDPs ranging between 67 and 85 µm.[23] The values of the mean marginal discrepancy values in the present study (63 ±25 µm) were slightly less than previous studies with the highest values at point 9,[4,13] probably due to different measurement methodologies. The CAD-CAM technique was unable to create a homogenous discrepancy along the tooth preparation in spite of the uniform 50-µm cement spacer setting used for FDP production. Different levels of adaptation were found for the FDPs at different measuring points in this study, and similar findings were reported in other studies.[4,13,22] The quality of acquisition, processing of the digital data, and the diameter and shape of the milling instruments may all influence the gap.

In the present study, the marginal adaptation presented the lowest values. Although several studies agreed that a marginal opening below 120 μm is clinically acceptable,[18,20] the highest mean marginal discrepancy of 63 μm was found at point 9 for CS, which is well below the clinical threshold. Marginal adaptation minimizes plaque retention preventing caries and pulpal irritation.[21] Wider discrepancies may be accepted with improved adhesive luting materials and protocols. The mean discrepancy values presented in this study are higher than those of previous studies, where a mean marginal discrepancy of 37 μm, a mid-axial discrepancy of 41 μm, an axioocclusal line angle of 55 μm, and an occlusal discrepancy of 127 were reported.[4] The difference may be explained by the adaptation procedures used before measurement.[23,45] The intaglio of the FDPs was not adjusted in this study.

A mean axial wall width of 122 μm might decrease the fracture strength of the restorations. CS Z6 showed the highest mean value of 90 μm, and the occlusal surface showed the largest discrepancy when both materials were used. This could reduce the space available for ceramic veneering.[22] The preparation form may have influenced the final results as the highest internal discrepancy could be related to the inability of the milling to reproduce fine details, especially in regions with sharp angles.[30] In this study, metal dies were used with a chamfer finish line and inclined occlusal surfaces. While the occlusal flat form produced adequate internal fit compared with the axial wall and central groove area, the chamfer and shoulder designs presented similar external marginal openings.[22] However, others have observed better marginal adaptation for shoulder than for chamfer preparations.[46]

The FDPs were scanned before ceramic veneering.[20,30] Marginal discrepancy differences have not been reported among the 3 stages of veneering application.[24] The 2 materials tested were milled from presintered blocks. Thus, shrinkage after sintering was taken into consideration by following the manufacturer`s guidelines for volume increase. This procedure required the scanning of each model separately and avoided framework duplication, allowing for standardization.

The micro-CT, nondestructive analysis method allowed 2D and 3D high-resolution investigation of internal discrepancy in any angle or position. This study evaluated the marginal fit in the y-z axes. However, insufficient radiographic contrast may have limited the accuracy of the analysis. The scanning procedure was performed without cementation to improve the contrast between the metal die and the framework. A limitation of this technique was that problems were encountered with determining the discrepancy, especially for the zirconia. Thus, the presence of small artifacts may also preclude the analysis of a 3D volumetric dimension of the discrepancy,[36] and the results obtained should also be verified in future studies with a cement filling the space between the metal die and the framework.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Three-unit FDPs made of presintered Co-Cr or zirconia showed similar marginal and internal discrepancy values, with the highest values in the occlusal regions and the lowest in the marginal regions.
2. Except for the occlusal region, the marginal and axial discrepancy values for presintered Co-Cr or zirconia 3-unit FDPs did not exceed a clinically acceptable 100 µm.
3. Marginal and internal discrepancy were similar for abutment tooth types (first premolar or first molar) but significantly lower for zirconia at some measurement points on the abutment tooth.

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TABLES

Table 1. Comparison of mean discrepancies at 9 measurement points based on materials (CS: Presintered Co-Cr; CZ: Presintered zirconia) and abutment teeth (Z4: first premolar; Z6: first molar). *significant difference (P<.05)

Mean ±SD	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
CS	46.85 ±18.25	75.39 ±27.1	83.53 ±29.48	133.51 ±28.25	187.84 ±39.57	158.13 ± 39.33	76.62 ±24.86	64.21 ±25.13	63.82 ±25.54
CZ	35.69 ±9.25	45.20 ±14.68	53.06 ±17.56	129.87 ±30.15	174.9 ±51.61	164.67 ±53.47	79.06 ± 18.38	75.83 ± 25.46	57.71 ±21.07
P	**.012***	**<0.001***	**<0.001***	**.668**	**.335**	**.632**	**.701**	**.119**	**.37**
Z4	42.97 ±18.20	56.45 ±23.15	63.97 ±22.77	137.51 ±27.76	199.40 ±48.95	182.28 ±52.96	77.51 ±24.57	80.65 ±26.17	62.78 ±24.28
Z6	39.56 ±12.1	64.13 ±29.3	72.61 ±33.23	125.87 ±29.54	163.35 ±35.26	140.52 ±26.72	78.16 ±18.60	59.39 ±20.72	58.75 ±22.76
P	**.449**	**.319**	**.299**	**.166**	**.005**	**<.001***	**.92**	**.003***	**.557**

Table 2. Comparison of mean gaps at 9 measurement points for 2 materials (CS: Presintered Co-Cr; CZ: Presintered zirconia) on each abutment teeth (Z4: first premolar; Z6: first molar).
*significant difference (P<.05)

Mean ±SD	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Z4 / CS	55 ±18.42	68.64 ±23.01	76.95 ±22.67	141.87 ±24.57	210.81 ±28.86	182.81 ±34.39	80.59 ±29.93	75.46 ±24.31	64.84 ±25.95
Z4 / CZ	30.95 ±6.17	44.27 ±16.34	50.99 ±14.22	133.15 ±31.09	198.99 ±62.39	181.75 ±68.41	74.44 ±19.1	85.83 ±27.98	60.72 ±23.44
P	**<0.001***	**.007***	**.003***	**.454**	**.268**	**.962**	**.556**	**.343**	**.687**
Z6/CS	38.7 ±14.58	82.13 ±30.12	90.11 ± 34.76	125.15 ±30.2	164.87 ±35.93	133.46 ±26.88	72.65 ±19.02	52.96 ±21.3	62.81 ±26.23
Z6/CZ	40.42 ±9.58	46.13 ±13.47	55.12 ± 20.82	126.59 ±30.18	161.82 ±36.1	147.58 ±25.72	83.67 ±17.18	65.82 ±18.81	54.7 ±18.94
P	**.735**	**.002***	**.008***	**.908**	**.837**	**.202**	**.151**	**.131**	**.395**

Table 3. Pairwise comparison for statistical difference based on measurement points (*P*<0.05)

Point/p	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
	2-9/<.001	**1,2-6/<.001**	**1, 4-6/<.001**	**1-9/<.001**	**1-4, 7-9/<.001**	**1-4, 7-9/<.001**	**1, 4-6/<.001**	**1, 4-6/<.001**	**1, 4-6/<.001**
All Materials					**6/.003**	**5/.003**	**2/<.001**		**7/<.001**
							9/<.001		
	2/.014	**1/.014**	**1, 4-6/<.001**	**1-3, 5, 7-9/<.001**	**1-4, 7-9/<.001**	**1-3, 7-9/<.001**	**1/.003**	**4-6/<.001**	**4-6/<.001**
CS	**3-6/<.001**	**4-6/<.001**			**6/<.001**	**5/<.001**	**4-6/<.001**		
	7/.003								
	3/.014	**4-7/<.001**	**1/.014**	**1-3/<.001**	**1-3/<.001**	**1-3/<.001**	**1-2/<.001**	**1/<.001**	**1/<.001**
CZ	**4-8/<.001**	**8/.002**	**4-6/<.001**	**5/.003**	**4/.003**	**6/.011**	**3/.003**	**2/.002**	**4-6/<.001**
	9/<.001		**7/.003**	**6/.011**	**7-9/<.001**	**7-9/<.001**	**4-6/<.001**	**4-6/<.001**	**7/<.001**
				7-9/<.001			**9/.001**		

FIGURES

Figure 1. Representative image of first molar (Z6) at microcomputed tomography in YZ-axis.

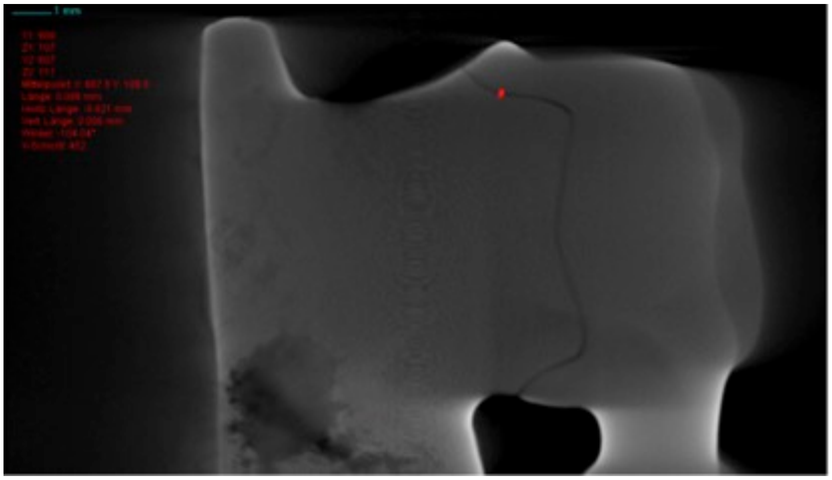

Figure 2. Nine measurement points selected for discrepancy measurements on each abutment.